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Nonrenewable energy cost and greenhouse gas emissions of a 1.5 MW solar power tower plant in China

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ABSTRACT

It is commonly assumed that renewable energy based systems have the potential to mitigate greenhouse gas emissions and save fossil energy from the grid. Nevertheless, any energy conversion systems need extra energy to deliver energy into society. It is necessary to estimate the total direct and indirect fossil energy cost and associated greenhouse gas emissions by any system over its entire life cycle. For the first MW class solar tower power plant in China, nonrenewable energy cost and greenhouse gas emissions are accounted respectively as 0.95 MJ/MJ and 0.04 kg CO_2-eq/MJ during its expected 20 years of operating life, corresponding to a net nonrenewable energy saving of 3.92E+08 GJ and greenhouse gas emission mitigation of 4.17E+04 tonne CO_2-eq compared to conventional thermal power systems in China.

Contents

1. Introduction

China's power and industrial process heat generation are heavily reliant upon coal-fired thermal power plants, which accounts for more than 70% of the total energy supply in the past [1], and results in a tremendous rise in greenhouse gas (GHG) emissions [2–13]. The total direct GHG emission of China as the world's second largest greenhouse gas emitter, amounted to 7456.12 Mtonne CO_2-eq by the commonly referred Intergovernmental Panel on Climate Change (IPCC) global warming potentials in 2007 [2]. Developing a clean technology such as concentrating solar thermal power would have strategic significance to shrink coal consumption and to cost-effectively accelerate the decarbonisation in the power sector and commercial and industrial process heat generation. The Chinese Government has undertaken a series of national programs to promote the development and utilization of clean and renewable energy, and the National People's Congress passed a law in February 2005 pledging to replace 10% of China's energy consumption with renewable energy resources by 2010 and 15% by 2020 [14]. According to the national Long- and Medium-term Plan on Renewable Energy, demonstration projects of solar thermal power plant are being constructed in desert areas in northwest China during the Eleventh Five-Year Planning (2006–2010), and the total existing capacity of solar thermal power will be expected to reach 50 MW

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Table 1
Completed and to be completed solar power tower stations in the world since 1980 (derived from [16–26]).

First year of operation	Location	Plant name	Capacity	Heat-transfer fluid	Thermal storage materials
1980	Italy	EURELIOS I	1.0 MW	Vapour	Nitrate/water
1981	Spain	SSPS	0.5 MW	Liquid sodium	Liquid sodium
1981	Japan	SUNSHINE	1.0 MW	Vapour	Nitrate/water
1982	America	Solar One	10.0 MW	Vapour	Heat transfer oil/rock
1982	Spain	CESA I	1.2 MW	Vapour	Nitrate
1983	America	MSEE/Cat B	1.0 MW	Nitrate	nitrate
1983	France	THEMIS	2.0 MW	Ternary nitrate	Ternary nitrate
1985	USSR	CES 5	5.0 MW	Vapour	Water/vapour
1993	Spain	TSA	1.0 MW	Air	Ceramic
1996	America	Solar Two	10.0 MW	Nitrate	nitrate
2001	Israel	Consolar	0.5 MW	Charge air	Fuel combination
2001	Spain	Solgate	0.3 MW	Charge air	Fuel combination
2005	China	HHU	75.0 kW	Air	None
2007	Spain	PS10	10.0 MW	Saturated vapour	Saturated water
2008	Israel	SEDC	4.0–6.0 MW	Superheated vapour	Water/vapour
2009	America	Sierra	5.0 MW	Superheated vapour	Water/vapour
2009	Spain	PS20	20.0 MW	Saturated vapour	Saturated water
Under construction	China	Dahan	1.5 MW	Superheated vapour	Oil/vapour
Under construction	Spain	Gemasolar	17.0 MW	Salt	Salt

by 2010, and 200 MW by 2020 [15]. With two-thirds of the territory enjoys over 2200 h of sunshine annually, with total solar radiation per unit area of over 5000 MJ/m^2, China has favorable conditions for solar energy development, especially in western regions.

Solar thermal power plants have a long history. Already in 1890 a steam engine has been powered by a solar concentrating collector [16]. During the 20th century, the availability of cheap fossil fuel led to a decline of interest in solar driven power plants. Only the so-called oil crisis in the 1970s caused a renaissance of solar technology [17]. There are now mainly four different concentrating solar thermal technology options, namely parabolic trough, tower, chimney and dish. In this paper, we focus on the solar power tower. Power tower plants are often defined by the options chosen for a heat transfer fluid, a thermal storage medium and for a power-conversion cycle. Heat transfer fluids may be water/vapour, molten nitrate salt, liquid metals or air. The thermal storage is often provided by phase change materials. Power tower systems usually achieve concentration ratios of 300–1500, and can operate at temperatures up to 1500 °C [18].

The idea of building a power tower plant was first suggested by scientists in the Soviet Union [19]. Then, a number of small pilot plants were constructed in Italy from 1965 to 1967. After a break of a few years, the power tower again attracted attention and consumed 60–70% of budgets [20] devoted to the conversion of sunlight into thermal energy at the end of 1970s. Table 1 reviews completed solar power tower stations in the world since 1980. EURELIOS I, the world's first experimental solar power plant in the megawatt range, was completed and fed electricity into the grid of the Italian National Electricity Board at the end of 1980 [21]. In the 1990s, pilot tests of the Solar One and Solar Two solar tower power projects were made by U.S. Department of Energy using molten salt technology for solar energy storage system in the Mojave Desert. In the past decade, the 10 MW Solar One and Solar Two heliostat demonstration projects have been decommissioned. Recently, an 11 MW solar power tower, which is the Europe's first commercial solar power tower plant, named PS10 was constructed near Seville, Spain in 2006, and has been grid-connected since early 2007 [22]. Another 20 MW tower in Spain, called PS20, reported successful tests in operation on land adjacent to the PS10 in April 2009. PS20 is now the world's second power tower plant in commercial use and the largest of the option [23]. Both PS10 and PS20 used water as the operating fluid, delivering saturated steam at 250 °C to turn an electricity-generating turbine. Spain also plans to build a third tower, the AZ20, with improvement upon the technologies used in PS10 and PS20 [23]. Nowadays, there are two power tower stations under construction (see Table 1) and will be operational in the near future. Meanwhile, some power tower projects are currently in the planning stage, such as BrightSource PPA5-7, eSolar 1 and 2 in America; AZ20, Almaden Plant in Spain [24].

In China, research on solar tower began in the middle 1970s. The first experimental simulation device for a solar tower was built in Tianjin City with a power of 1 kW. However, because some problems with regard to craftsmanship, materials and components had not been solved, and national outlays for the technology development were not enough, and the solar tower power project only progressed slowly [25]. In the tenth Five-Year Planning, the Chinese government increased capital input and policy support to promote the development and utilization of solar power. The centerpiece of the government's solar energy program is proceeding from small to large tests. In this context, the first commercial solar tower power plant in China was constructed in Nanjing City in 2005, and achieves an output of 70 kW. After this, several companies are developing larger commercial solar thermal power plants in northwestern China through cooperation with foreign countries [26].

Similar to almost all the renewable energy based systems, solar power systems are often considered to deliver energy without causing any depletion of fossil energy resources and also without giving rise to any environmental damage. However, previous studies emphasized the need for estimation of total direct and indirect energy demanded and associated GHG emissions by any system over its entire life cycle (e.g., [27–31]). Baron compared the results of net energy analyses performed for solar thermal and photovoltaic energy systems with that of conventional power generating systems in 1984 [32]. Trieb et al. [33] compared different solar electricity technologies taking into consideration their performance, costs and environmental impact in 1997. The next year, Lenzen [34] represented a GHG analysis of three types of solar power plants. Nevertheless, no study on nonrenewable energy (NE) cost and GHG emissions of Chinese solar power tower stations can be found in publications, though extensive research on various renewable energy sources and systems in the society has been performed (e.g., [35–52]).

This paper is on a 1.5 MW solar tower plant in suburban Beijing, designed by China Huadian Engineering Co., Ltd. in China Huadian Corporation and the Institute of Electrical Engineering in the Chinese Academy of Sciences, sponsored by the Ministry of Science and Technology of China. The program for the first MW class solar tower in China has being funded from 2006. If the program is assessed

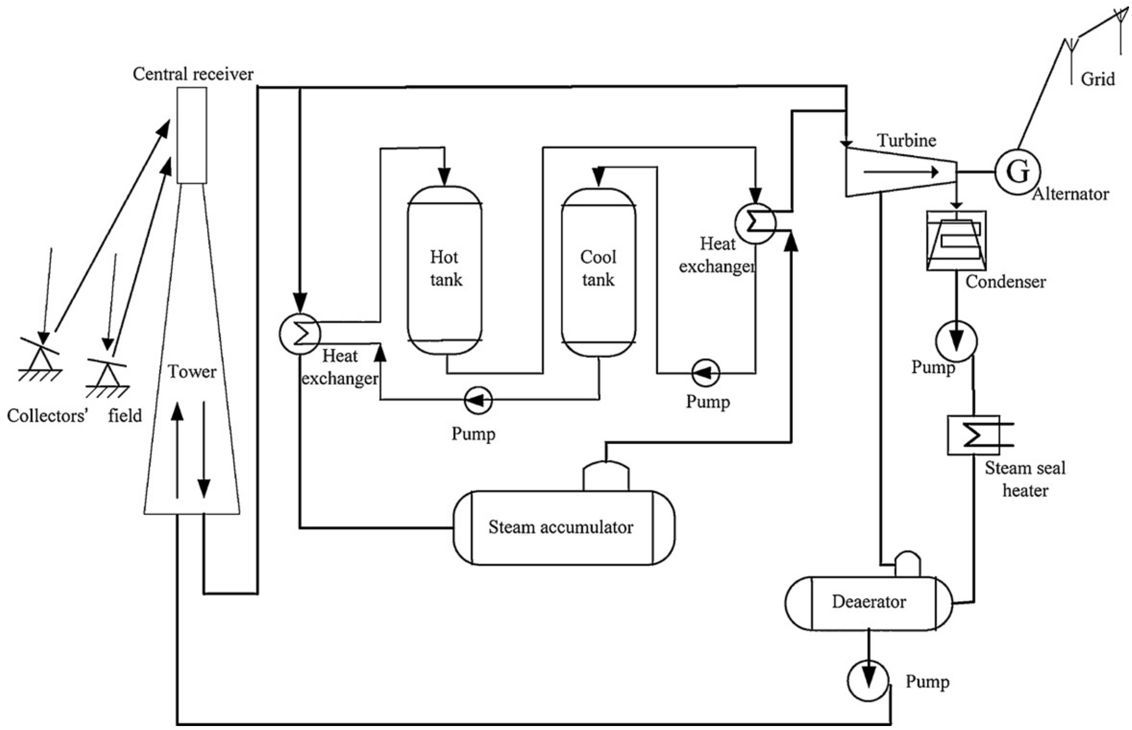

Fig. 1. The layout plan of the proposed solar power tower plant in Beijing, China.

successful, it could be expanded to a 5–10 MW project by 2015. This study conducts a GHG emission estimation and energy analysis on the 1.5 MW solar tower, and determines GHG mitigation and resource conservation achievable by solar energy.

2. Method

For NE use associated with its believed dominant role in the climate change, Chen et al. [53] suggested an indicator of NEIED, defined as NE investment in energy delivered to address how much NE instead of inclusive energy is consumed to produce a presumed renewable energy, i.e., NEIED = NE/E_{out}, where NE is the nonrenewable energy used directly and indirectly in the production process, and E_{out} is the net energy output of the concerned energy system, for the present case the net electricity output from the studied solar power plant. As for NE calculation, firstly, an inventory of all input nonrenewable energy and material flows to the whole chain of processes is performed. Secondly, input flows are then multiplied by suitable conversion coefficients which express the unit NE demand in the production or preparation of each input. Similarly, the GHG emissions associated with NE cost can be calculated as input flows multiplied by suitable conversion coefficients which express the unit GHG emissions in the production or preparation of each input.

In this study, the conversion coefficients associated with NE cost are valuated by subtracting renewable energy inputs into the society in an environmental extended input–output analysis (IOA) performed by Zhou [54], with embodiment intensities for all the 151 kinds of typical commodities in Chinese economy conclusively provided as a systematic account of embodied ecological elements in the Chinese national economy. Conversion coefficients of GHG emissions can also be found in Zhou [54].

Due to the difficulty in collecting relevant data and the time constraints, certain issues are excluded in all processes considered to make this analysis easy to accomplish: namely, (1) the fossil fuels consumed and GHG emissions in all transportation processes; (2) the fossil energy input required and the GHG emissions output caused by labor and machines in the construction process.

3. Inventory of the power tower

The $14.6 million power tower project, rated at 1.5 MW, will comprise 100 curved heliostats to concentrate radiation on a 100-meter-tall tower, using water as the heat transfer fluid. The 1.5 MW solar thermal power plant is located in Yanqing County (115°44′E–116°34′E, 40°16′N–40°47′N) in the northwest of Beijing Municipality, covers 236.8 Chinese mu (157,867 m^2), including 208 Chinese mu (138,667 m^2) of solar collector's field and 28.8 Chinese mu (19,200 m^2) of power station. The auxiliary power consumption rate is designed to be less than 15%. Electricity generated by the solar power plant will be connected to a 100 kW substation about 3 km away. Taking two years to construct, the project is designed with an operational life of 20 years.

The general layout plan of the proposed power tower is illustrated as in Fig. 1. The power tower station is a national pilot project, which includes a tower having a base and a solar heat absorber being at the top of the tower, a field of heliostats disposed around the base of the tower, a heat storage system, a turbo-generator system to convert the thermal energy into electricity, and a control room combined with a test base. The solar radiation is reflected and concentrated into the central heat absorber by a hundred heliostats that position themselves automatically. The parameters of output superheating steam are 2.5 MPa, 400 °C, and 8.4 tonne/h steam flux is produced. The high pressure superheated steam from the receiver flows along two different pipes: one stream goes into the high-temperature heat exchanger in the solar energy storage system; the other channel of the superheating steam enters directly into a turbine to generate power.

To make full use of the land on which the plant will be based, the design also calls for growing crops under the heliostats. All of the detailed data referring to the studied power tower station are from

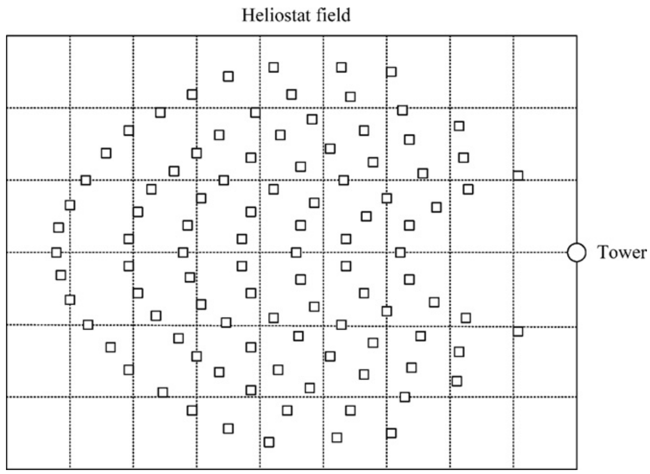

Fig. 2. Solar heliostat field and receiver.

sources provided by several institutes, university and companies [55] led by the Institute of Electrical Engineering of the Chinese Academy of Sciences.

The power tower performance is studied in five major parts, namely:

(1) Solar heliostat field and receiver;
(2) Solar energy storage system;
(3) Turbo-generator system;
(4) Control system and test base;
(5) Operation and maintenance.

3.1. Solar heliostat field and receiver

The heliostat field is divided into seven curving rows. Each row is in turn subdivided into 9–19 heliostats, as shown in Fig. 2. The distance from the first row to the tower is about 80 m. The reflectivity of the heliostat clean mirror is about 90%; the yearly reflectivity is about 75%. A heliostat is a device incorporating a mirror which moves so as to keep reflecting sunlight towards a predetermined target or receiver, despite the sun's apparent motions in the sky [56]. To do this, each heliostat must have its own dual-axis tracking control system which continuously focuses beam radiation towards the receiver during collection. Glass plays an important role as transparent materials of heliostats in solar power tower systems. The optical transparency, chemical durability and manufacturability of glass make it a critical material for solar energy applications [57]. There are many kinds of heliostats, but the general function of the glass component is common: glass transmits desirable solar radiation to a thermal storage unit, while providing chemical and structural protection of that active component from the ambient conditions [57]. Each heliostat used in the project generally consists of a foundation at a depth of 2 m, a steel structural support at a height of 4.5 m covering a net aperture area of 0.2 m^2, a layer of reflective silver, and a top protective layer of thick glass with a thickness of 5 cm and an area of 100 m^2.

The receiver unit, which lies on the east of the heliostat field, consists of a foundation, a 100 m steel tower with a solar heat absorber at the top. The tower foundation is made on site and consists of filling up a hole (typical size 50 m × 50 m and 6 m deep) with steel reinforced concrete. The bottom of the steel tower covers an area of 140 m^2. The absorber is designed to accept the large and variable heat flux which results from the concentration of the solar radiation by the heliostats, and is the most complex part of the receiver unit. There are generally two types of absorber designs: the external type and the cavity type. In the power tower, the absorber is a cavity type, consisting of heat pipes, the thermal insulating course, cooling runner, and secondary condenser. The cavity absorber is designed to maximize the absorption of the entering solar radiation and meanwhile to minimize heat losses by convection and radiation to the ambient. The designed cavity absorber can operate at temperatures range from 300 °C to 1200 °C.

Table 2
Design characteristics of the turbine.

Type	Condensing steam turbine
Rated power	1.5 MW
Main steam pressure	2.35 MPa
Rated steam flow	8.4 tonne/h
Cylinder	Single
Shaft	Single

Table 3
Design characteristics of the generator.

Rated power	1.5 MW
Rated voltage	10.5 kV
Rated speed	1500 r/min
Power factor	0.8
Exciting mode	Silicon controlled rectifier excitation

3.2. Solar energy storage system

The function of the solar energy storage system is to store the heat from the heat transfer fluid for a few hours to allow electricity production during periods of peak need, even if the solar radiation is not available. The storage system capacity of the project allows 1 h full load operation. The proposed power tower energy storage system consists of two oil tanks and a steam accumulator (see Fig. 1). The synthetic oil is cycled between the two oil tanks to produce saturated steam and superheated steam. Further materials including concrete and molten salt used in the construction of the plant are also studied [58]. The volume of each oil tank is 10 m^3, while the volume of steam accumulator is 90 m^3. The tank foundation consists of filling up a hole of 200 m^3 with steel reinforced concrete.

In addition, a two-stage thermal-energy storage system is planned to replace the energy storage system mentioned above in the future. The two-stage thermal-energy storage system is proposed for a newly designed power tower system layout combined a saturated steam with a combustion gas turbine generator, which is different from the existing solar-power tower plants.

3.3. Turbo-generator system

The turbo-generator system consists of a turbo-generator set and distribution equipment. The turbo-generator set, which is located in a combination workshop, consists of a turbine and a generator, and some other equipment including an auxiliary heating boiler, a cooling tower, a de-aerator, a steam seal heater and a condenser (see Fig. 1). The turbo-generator set uses the superheated steam from the storage system or from the receiver as a heat source and water drawn from a nearby well as a cooling source. The design characteristics of the turbine and the generator are listed in Tables 2 and 3. Owing to the chemical-stability limits of synthetic oil, the maximum working temperature of the high-temperature storage device is limited under 350 °C which is lower than the inlet temperature required by turbine-generator. Thus an auxiliary heating boiler is needed for the electricity power generation. The steam seal heater and condenser are both heat exchangers made of copper tubes allowing heat transfer between the fluid and both the hot and cold sources. The electric current produced by the generator is then discharged into the local electric grid through the distribution system, which mainly consists of three transformers and cable.

3.4. Control room and test base

The most important function of the control system is to keep the power tower outlet temperature near a desired set point or reference temperature [59]. In addition, when the power tower station is out of work, the control system orients the heliostats in a safe direction in order to keep the receiver from damage. The control system of this project mainly consists of five computers.

There is also a test base in the same building with the control room. The objectives of the project include building a testing solar thermal platform. It will be available for the different types of testing, including testing the heliostat optical performance, water/steam receiver, molten salt receiver, air receiver, the high temperature transportation loop, the thermal storage methods and the high efficiency thermodynamic power cycle.

3.5. Operation and maintenance

The auxiliary heating boiler burns oil to heat the steam. The oil consumption is about 1 tonne per week. As for water consumption, cleaning the collectors uses 1 tonne of water per day; circulating cooling water is used at the rate of 35 tonne per day; chemical feed water is consumed at 14 tonne per day; auxiliary cooling water is used at 30 tonne per day; domestic water consumption is 20 tonne per day. The turbo-generator system operates with a daily water consumption of 100 tonne.

Table 4
The annual performance parameters of the studied power tower.

Parameter	Designed value
Mirror reflectivity yearly	0.75
Field efficiency yearly	0.74
Mirror cleanliness yearly	0.75
Receiver efficiency	0.90
Storage factor	0.99
Intercept factor	0.95

3.6. Predicted annual electricity output

Researchers of the Institute of Electrical Engineering of the Chinese Academy of Sciences developed a software tool, HFLD [60], for heliostat field layout design and performance calculation. The simulation results from HFLD approximately agree with the published heliostat field efficiency data from Spain PS10 [60]. Based on that, the performance of the studied power tower is simulated by the HFLD software. The annual performance parameters designed of the power tower is listed in Table 4. The annual sum of direct normal

Table 5
NE cost and GHG emissions of the proposed solar tower during 20 years of operating time.

Item	Component	Material	Quantity[a]	Unit	NE intensity[b] (MJ/Unit)	GHG intensity[b] (tonne CO_2-eq/unit)	NE (MJ)	GHG (tonne CO_2-eq)
Solar collectors' field								
Solar collectors	Mirror	Glass	40.00	m^3	3.02E+05	1.50	1.21E+07	60.00
	Bracket	Steel	1,800.00	tonne	3.26E+04	1.39	5.87E+07	2,502.00
	Foundation	Concrete	3,200.00	m^3	6.03E+03	0.53	1.93E+07	1,696.00
		Steel	480.00	tonne	3.26E+04	1.39	1.56E+07	667.20
Receiver	Tower	Steel	400.00	tonne	3.26E+04	1.39	1.30E+07	556.00
	Absorber	Steel	1.50	tonne	3.26E+04	1.39	4.89E+04	2.09
	Foundation	Concrete	250.00	m^3	6.03E+03	0.53	1.51E+06	132.50
		Steel	37.50	tonne	3.26E+04	1.39	1.22E+06	52.13
Subtotal							1.21E+08	5,667.91
Solar energy storage system								
	Oil tank			tonne	4.22E+05	1.40	7.09E+06	
			16.80					23.52
	Steam accumulator		35.50	tonne	3.42E+04	1.30	1.21E+06	46.15
	Foundation	Concrete	200.00	m^3	6.03E+03	0.53	1.21E+06	106.00
Subtotal		Steel	30.00	tonne	3.26E+04	1.39	9.78E+05	41.70
							1.05E+07	217.37
Turbo-generator system								
Turbo-generator set	Turbo-generator		10.50	tonne	9.28E+04	2.47	9.74E+05	25.94
	Utility boiler		8.40	tonne	4.01E+05	1.40	3.37E+06	11.76
	Cooling tower		6.00	tonne	3.79E+04	1.37	2.27E+05	8.22
	De-aerator		5.35	tonne	1.62E+05	4.85	8.64E+05	25.95
	Steam seal heater		5.50	tonne	3.79E+04	1.37	2.08E+05	7.54
	Condenser		5.00	tonne	3.79E+04	1.37	1.90E+05	6.85
Distribution equipment	Transformer	Silica	0.60	tonne	3.06E+04	0.60	1.84E+04	0.36
		Steel	10.80	tonne	3.26E+04	1.39	3.52E+05	15.01
		Copper	4.80	tonne	1.64E+05	4.70	7.87E+05	22.56
	Cable	Copper	25.37	tonne	1.64E+05	4.70	4.16E+06	119.22
Combination workshop	Room	Brick	890.64	tonne	6.03E+03	0.53	5.37E+06	472.04
	Foundation	Concrete	430.00	m^3	6.03E+03	0.53	2.59E+06	227.90
		Steel	64.50	tonne	3.26E+04	1.39	2.10E+06	89.66
Subtotal							2.12E+07	1,032.99
Control room and test base								
	Computer		5.00		4.38E+05	11.27	2.19E+06	56.35
	Room	Brick	2,354.40	tonne	6.03E+03	0.53	1.42E+07	1,247.83
	Foundation	Concrete	500.00	m^3	6.03E+03	0.53	3.02E+06	265.00
		Steel	75.00	tonne	3.26E+04	1.39	2.44E+06	104.25
Subtotal							2.19E+07	1,673.43
Maintenance and operation								
	Water		0.73	Mtonne	3.29E+04	0.81	2.40E+04	0.59
	Oil		1,042.86	tonne	4.37E+04	0.40	4.56E+07	417.14
Subtotal							4.56E+07	417.73
Total							2.21E+08	9.01E+03

[a] [54].
[b] [55].

incident used in the simulation process is around 2200 kWh/m^2 and the annual total solar to electric efficiency is 14.6% with assumed 2700 h of annual operation time. Those assumptions are acceptable for estimation on energy balance [60]. The power tower station can achieve gross electrical energy of 3.22 GWh under the reasonably assumed annual meteorological conditions [60].

4. Results and discussions

The power tower life cycle, NE cost and GHG emissions are listed in Table 5.

The NE requirement of the whole solar tower power system is 2.21E+08 MJ. The largest contributor to NE consumption is the solar heliostat field and receiver system (55%). About 21% of NE cost is related to maintenance and operation (see Fig. 3). As described in Section 3, the annual electricity output to assess grid is 3.22 GWh. The total electricity output for a 20 years solar tower is thus summed up to be 2.32E+08 MJ. Thus, the nonrenewability indicator of NEIDE is calculated to be 0.95.

Accounting of GHG emissions caused due to construction and operation of the solar tower has been done in a way similar as for the NE analysis (see Table 5). The total GHG emissions for a 20-year solar tower power plant are summed up to be 9.01E+03 tonne CO_2-eq. An embodied GHG emission of 0.04 kg CO_2-eq/MJ is found for the solar tower. Analysis of the results of Fig. 4 shows that 95% are in the construction of the solar power tower plant, while 5% of the total GHG emissions are caused in the maintenance and operation process.

In contrast to most renewable energy based energy systems and to solar power tower systems in particular, conventional power systems and hence thermal power plants consume nonrenewable energy resources and generate GHG into the atmosphere mainly during their operational life for the generation of electricity. In a rough estimation done in our early work, the national average NE intensity and GHG emission intensities of thermal power are 2.64 MJ/MJ and 0.22 kg CO_2-eq/MJ respectively [53]. The coal power system therefore tends to consume about 2.78 times NE and 5.50 times GHG emissions compared to the considered solar tower for per unit generation of electric power. Meanwhile, 1.69 MJ of NE and 0.18 kg CO_2-eq is saved per MJ of solar electricity output. Thus the NE saving and GHG mitigation during 20 years of operating time have been estimated as 3.92E+08 GJ and 4.17E+04 tonne CO_2-eq.

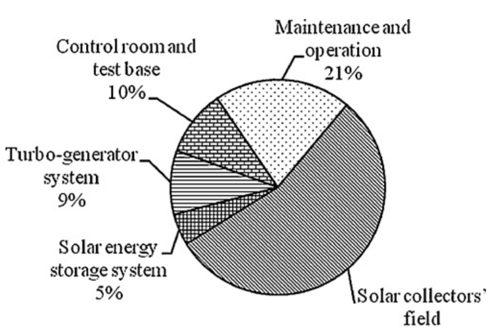

Fig. 3. Percentages of NE cost for each stage in a Chinese solar power tower life cycle.

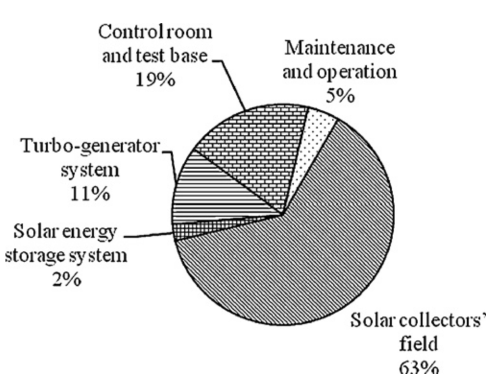

Fig. 4. Percentages of GHG emissions linked to each stage in a Chinese solar power tower life cycle.

5. Concluding remarks

Along with the execution of Renewable Energy Law since 2006 in China, the solar electricity industry has been developed quickly in an unprecedented way. Solar thermal power will make a real impact if it leads to large scale electrical power generation. Non-renewable energy costs and GHG emissions of the studied power tower plant mostly arise primarily from materials processing and manufacture. During the operation and maintenance phase, the plant has relatively few nonrenewable energy costs and related GHG emissions. The nonrenewable energy cost of the studied solar power tower plant is estimated as 0.95 MJ for 1 MJ electricity produced, which is larger than that of the power tower studied formerly by Baron in 1984 [32]. The GHG emissions of the power tower is found as 0.04 kg CO_2-eq/MJ, which is similar to the one reported by Lenzen in 1999 [34]. But compared to thermal power systems, solar towers would achieve significant fossil energy saving and GHG emission mitigation in China, though a considerable amount of developmental work has to be carried out towards commercialization.

The results on nonrenewable energy cost and greenhouse gas emissions has essential implications for the solar power tower manufacturer, power generating stakeholders and decision makers, and would play an important role in proper project design and in getting a subsequent project public acceptance, though some other potential environmental implications of land use, visual impacts, noise intrusion, water resources, health and safety and social impacts [61] remain to be quantified in further studies for the wide-scale deployment of power towers.

Acknowledgments

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